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RESEARCH ARTICLE

Appropriate forestry practices for the management of austrian pine (*Pinus nigra* Arn.) plantations with understory of manna ash (*Fraxinus ornus* L.) in Sofia surrounding mountains

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Abstract

The object of the current study are Austrian pine (*Pinus nigra* Arn.) plantations with an understory of Manna ash (*Fraxinus ornus* L.), located in the mountain areas near Sofia, Bulgaria on altitude from 700 to 850 m a.s.l. The aim is to study the natural regeneration processes taking place in the plantations and to provide guidelines for their management. It has been established that their transformation into deciduous stands is a natural process that is currently ongoing. The new generation of trees consists mainly of native oak species and their natural companions. However, the Manna ash understory is overgrowing and silencing the seedlings. The amount of seedlings depends on the forest site and increases as growing conditions improve. With the increase of canopy density, understory density decreases rapidly, while the amount of seedlings does not change significantly. With the increase of stand age, the amount of seedlings increases at the expense of the understory. Increasing the height of the understory results in significant loss of seedlings. In order to create conditions for successful transformation of the pine plantations with economically valuable autochthonous species, it is recommended to manage them at a canopy density above 0.6 as long as possible. Usually, a sufficient amount of seedlings is available after the stand age of 65, when the felling for their transformation can also begin. Forest sites with better conditions have seedlings present in the entire area, while in forest sites with worse conditions their distribution is uneven. In the first years of the felling the number of required thinnings depends on the height of the understory, which should not be allowed to exceed 120 cm until the new stand forms a canopy.

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Keywords
conifer stands, Austrian pine, Manna ash, understory, seedlings, transformation

Introduction

In the coniferous plantations in Bulgaria, created at lower altitude outside their habitat, intensive succession processes are taking place towards the regeneration of native broadleaf vegetation (Popov et al., 2018). Natural conifer regeneration occurs only in extremely rare cases. Usually the seedlings are from native species (oaks and their natural companions), as well as seedlings of various tree and shrub species (*Fraxinus ornus* L.), *Carpinus orientalis* Mill., *Crataegus monogyna* L., *Cornus mass* L., *Prunus spinosa* L., *Rosa canina* L., etc.). Typically, the understory species take a serious upper hand in the canopy layer and there is a real danger that they will define the appearance of the new generation of forest. This would return the ecosystem to an early succession stage of shrub vegetation, which is highly undesirable from a forestry point of view.

In Austrian pine plantations both in Bulgaria and in other European countries, a significant understory cover of Manna ash (*Fraxinus ornus* L.) is often observed (Glogov, 2003; Kalapos, Csontos, 2003; Wallmann, Stingl, 2011). The relationship – edificatory species–Austrian pine with dominant species in the canopy layer the Manna ash, is also found in natural phytocoenoses, such as the association *Fraxino orni - Pinetum nigrae* Martin-Bosse 1967 (class *Erico-Pinetea* Horvat 1959, (Wallnöfer, 1993).

Manna ash is the most widespread ash species in Bulgaria up to 1200 m a.s.l. (Velchev, 1982; Delkov, 1988). A large part of the coniferous plantations in the country were created after reconstruction of the so-called in the recent past "low-productive" and "low-value" forests, in which the Manna ash is a constant participant (Georgiev et al., 1965; Garelkov et al., 1969). These include a number of forest types: mixed forests of Austrian oak and Manna ash; Manna ash forests intermixed with *Carpinus orientalis*; mixed forests of *Fraxinus ornus*, *Tilia tomentosa*, *Ulmus minor* and *Acer*, etc. (Bondev, 1991). Due to its short seed germination period and rapid growth at an early age, as well as its ability to regenerate by vegetative shoots, the Manna ash easily occupies areas in the conifer plantations (Glogov, 2017).

Silvicultural studies of the species have focused mainly on its role in regeneration processes and the extent to which it negatively affects the recovery of native forest edificatory species (Borhidi, 1956; Csontos et al., 1996, 2001; Zlatanov, 2003; Trájer et al., 2016; Glogov et al., 2019). With its rapid growth and the danger of suppressing the seedlings not only through shading but also through competition for soil moisture, the Manna ash is a serious competitor to oaks at an early age and its control is a major concern for foresters (Ivanov, 1959; Dakov et al., 1960; Kostov, Stiptsov, 2004). The needed measures for its regulation require both specific silviculture interventions and comprehensive planning regarding conifer stands management. The complexity of

the issue increases due to the fact that the natural regeneration processes occurring in them haven't yet been elucidated and described by forest science. As a result, the measures to mitigate the spread of the Manna ash are limited to cutting it down during fellings, which usually does not have the desired effect.

The aim of the study is to investigate the natural regeneration processes in Austrian pine plantations with an understory of Manna ash in Bulgaria and to provide general silvicultural guidelines for their management with regard to their successful transformation with valuable native species.

Methods

The object of study are Austrian pine plantations with an understory of Manna ash in the mountains around the city of Sofia, Bulgaria. In 2021, 15 sample plots (SP 1 to 15) were positioned - 3 sample plots in each of the following mountains - Sofiyska mountain, Lozenska, Plana, Vitosha and Lyulin Mountain (Fig. 1). The area of every SP is 200 m^2.

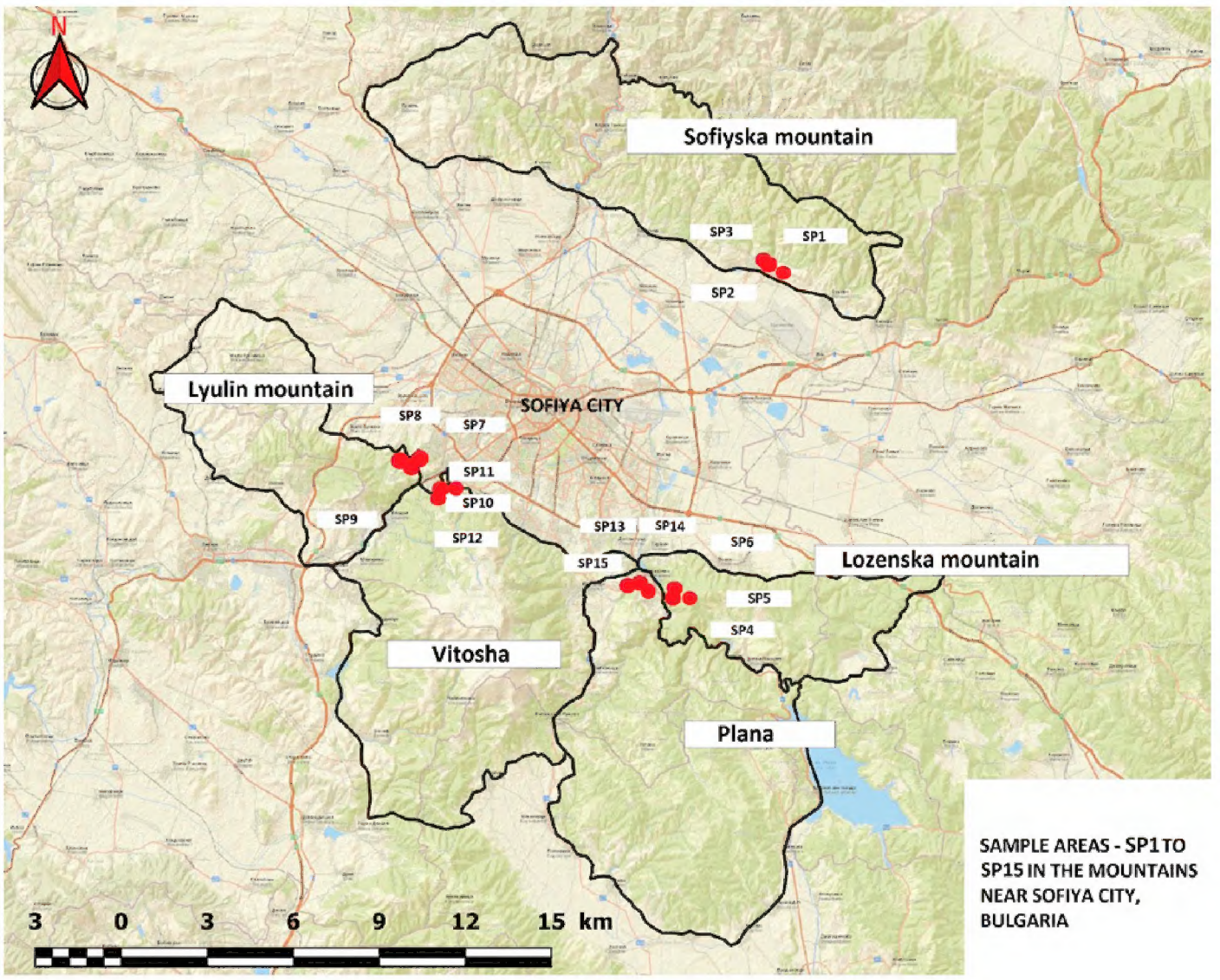

Fig. 1. Studied sites (sample plots)

The studied stands are monodominant by Austrian pine at altitudes ranging from 700 to 850 m a.s.l. Their age varies from 55 to 80 and the canopy density ranges from

55% to 75%. Forest sites (FS) range from poor and dry (type B1), medium to fertile, fresh to moist (type CD2,3) (Table 1). The nomenclature of Pogrebnyak (1955) is used for indication of soil fertility and soil moisture, as follows:

Soil fertility: A – very poor; AB – very poor to poor; B – poor; BC – poor to medium fertile; C – medium fertile; CD – medium fertile to fertile; D – fertile.

Soil moisture: 1 – dry; 1, 2 – dry to fresh; 2 – fresh; 2, 3 – fresh to moist; 3 – moist; 3, 4 – moist to wet; 4 – wet.

One transect with 10 m length and 2 m width is laid in every SP. The following conclusions were made – all trees and shrubs lying below the main stand of Austrian pine, their species, number and height. Determination and nomenclature of plant species follows Delipavlov, Cheshmedjiev (2003), the Latin name for the sessile oak is *Quercus petraea* (Matt.) Liebl., according to the concept of Fortini et al. (2015).

The registered species were grouped into two categories - seedlings and understory. In the category "seedlings" are placed young individuals of economically valuable tree species, which are desirable to form the main stand in the new forest generation. Of the species found, these are *Quercus petraea, Quercus cerris, Quercus frainetto, Quercus pubescens, Fagus sylvatica, Carpinus betulus, Tilia tomentosa, Tilia platiphyllos, Pinus nigra, Acer pseudoplatanus, Castanea sativa, Robinia pseudoacacia, Acer campestre* and *Sorbus torminalis.*

The category "understory" includes individuals of shrub and small tree species that do not reach the height of the main tree species. Of the species found, these are: *Fraxinus ornus* (which strongly dominates the understory), *Carpinus orientalis, Syringa vulgaris, Crataegus monogyna, Prunus mahaleb, Prunus cerasifera, Corylus avellana, Acer tataricum, Clematis vitalba, Malus sylvestris, Cotinus coggygria, Cornus sanguinea, Juniperus communis, Ligustrum vulgare, Rosa canina, Viburnum lantana, Laburnum anagyroides* and *Euonymus verrucosus.*

For the purpose of the study, the amount of seedlings and understory (number of individuals) was recalculated per 1 ha. The average height of the seedlings and understory was calculated as all of the measured heights of all individuals, falling into the respective category, were divided into their number (Table 1). For each transect, the slope is defined dimensionally as the percent projective canopy cover of the main stand.

Tukey's box plot diagrams (Molle, 2012), grouped by the respective factor levels, were used to visualize the variation of the variables. This representation is an essential element of Exploratory Data Analysis (EDA), aimed primarily at revealing the structure of data with subsequent construction of models and identification of relationships between variables (Tukey, 1977).

The R library ggplot2 (Wickham, 2016), which implements the grammar of graphics data visualization approach, was used to construct the diagrams.

Standard correlation analysis was applied to investigate the presence of linear correlations after pre-testing variable distributions. To calculate the correlation coefficient and check its statistical significance, functions from the base-package of the R language (R Core Team, 2022) were used. They were also used to visualize the zone

Table 1. Characteristics of the studied sites (SP)

Studied sites (SP)	Forest site (FS)	Tree composition	Age, years	Canopy density, %	Number of understory species per hectare	Average height of understory, cm	Number of seedlings per hectare	Average height of seedlings, cm
SP 1	B_1	*Pinus nigra* 100%	50	60	37500	156	500	20
SP 2	B_1	*Pinus nigra* 100%	50	65	14500	116	1000	20
SP 3	B_1	*Pinus nigra* 100%	50	75	8000	36	4500	10
SP 4	$B_{1,2}$	*Pinus nigra* 100%	55	70	18000	99	10500	35
SP 5	$B_{1,2}$	*Pinus nigra* 100%	55	65	23500	133	2500	27
SP 6	$B_{1,2}$	*Pinus nigra* 100%	55	60	38500	89	14000	79
SP 7	C_2	*Pinus nigra* 90%, *Carpinus betulus* 10%	75	55	36500	118	12500	125
SP 8	C_2	*Pinus nigra* 90%, *Fraxinus angustifolia 10%*	75	65	32500	77	6000	36
SP 9	C_2	*Pinus nigra* 90%, 10%	55	75	9500	100	8000	87
SP 10	$CD_{2,3}$	*Pinus nigra* 90%,, *Pinus sylvestris* 10%	80	75	5500	108	15500	65
SP 11	$CD_{2,3}$	*Pinus nigra* 90%,, *Pinus sylvestris* 10%	80	75	4000	63	22500	44
SP 12	$CD_{2,3}$	*Pinus nigra* 90%,, *Pinus sylvestris* 10%	80	65	14000	153	13500	62
SP 13	$B_{1,2}$	*Pinus nigra* 100%	55	65	44000	78	8000	69
SP 14	$B_{1,2}$	*Pinus nigra* 100%	55	70	25000	124	3500	18
SP 15	$B_{1,2}$	*Pinus nigra* 100%	55	55	40000	81	7500	52

of tolerance of the location of the points in which the normality hypothesis is not rejected.

Linear regression models were built using the tools of the stats package in the R language (R Core Team, 2022). The necessary validity checks of the models, as well as their varieties, were also implemented using the functions of this package. Multiple comparison methods (post-hoc methods) were also used to assess the statistical significance of differences between three or more group means when variance was evidenced by standard ANOVA.

In the absence of an overall statistically proven model, the homogeneity of the data was checked for the presence of clustering in more than one cluster. Checking for the presence of clusters was performed using the K-means algorithm (Hartigan, Wong, 1979).

Results

The Manna ash strongly dominates the understory in the studied Austrian pine plantations - it forms 65% of the total understory in the sample plots. The seedlings are mostly oaks - they form 73% of its quantity. The remaining 27% is accounted for by their natural companions. Of the oaks, Sessile oak (*Q. petraea*) is the most common, covering over half (53%) of the total amount of the seedlings. The amount of Turkey oak (*Q. cerris*) and Hungarian oak (*Q. frainetto*) is considerably less - at 11% and 8%,

Fig. 2. Sample plot № 8 (left)

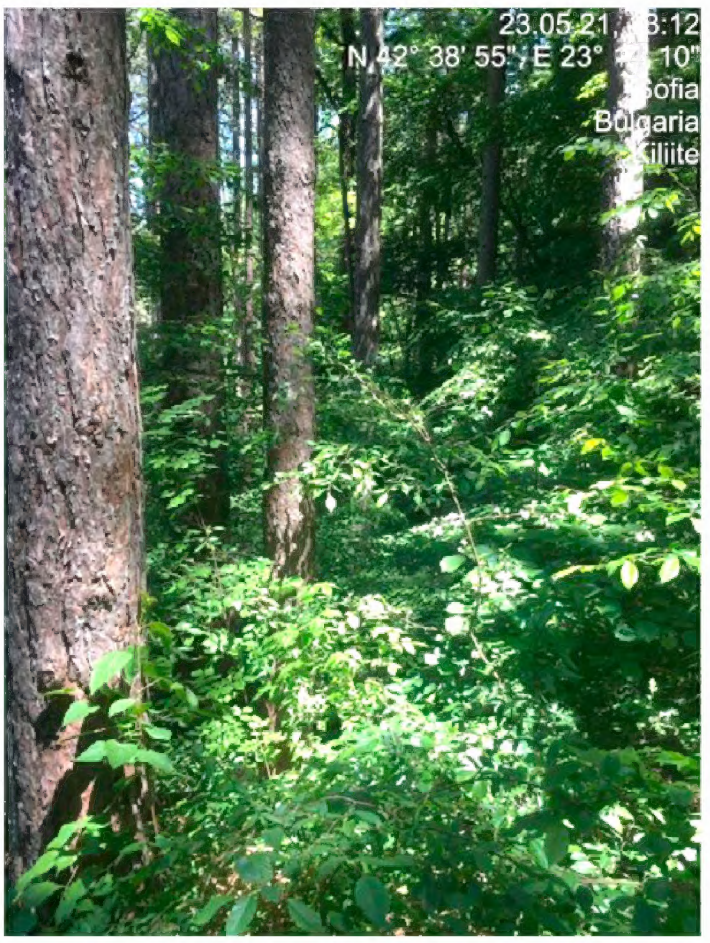

Fig. 3. Sample plot №10 (right)

respectively, and seedlings of Pubescent oak (*Q. pubescens*) are almost absent (0.4% of the total). Austrian pine seedlings, which is the main tree species in the studied stands, are practically absent. It is found in only one of the SPs and its quantity is negligible (less than 500 pcs/ha).

In all sample plots, the amount and average height of understory is greater than that of seedlings, i.e., the understory definitely outgrows the seedlings (Fig. 2 and 3).

The amount of understory is statistically proven ($p < 0.01$) to vary with respect to the forest site (FS). The resulting ANOVA table is as follows:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
FS	3	356166667	118722222	7.743	0.00468 **
Residuals	11	168666667	153333333		

The variation of the amount of seedlings by site index is graphically represented by a box plot diagram on Fig. 4. It can be seen that the amount of seedlings increases as growth conditions improve. On poor and dry forest sites (type B_1), the amount of seedlings is very small (between 500 and 4500 pcs/ha) in all sample areas. On medium-fertile and fresh sites ($B_{1,2}$ and C_2) the number of seedlings is between 5000 and 15000 pcs/ha. From the overlap of IQR for the B1,2 and C2 forest sites, it follows that there is no statistically proven difference between their means. On the medium fertile to fertile (type $CD_{2,3}$) the amount of seedlings is between 15,000 and 25,000 pcs/ha. Between these three levels in growth conditions, differences in the amount of seedlings are statistically significant.

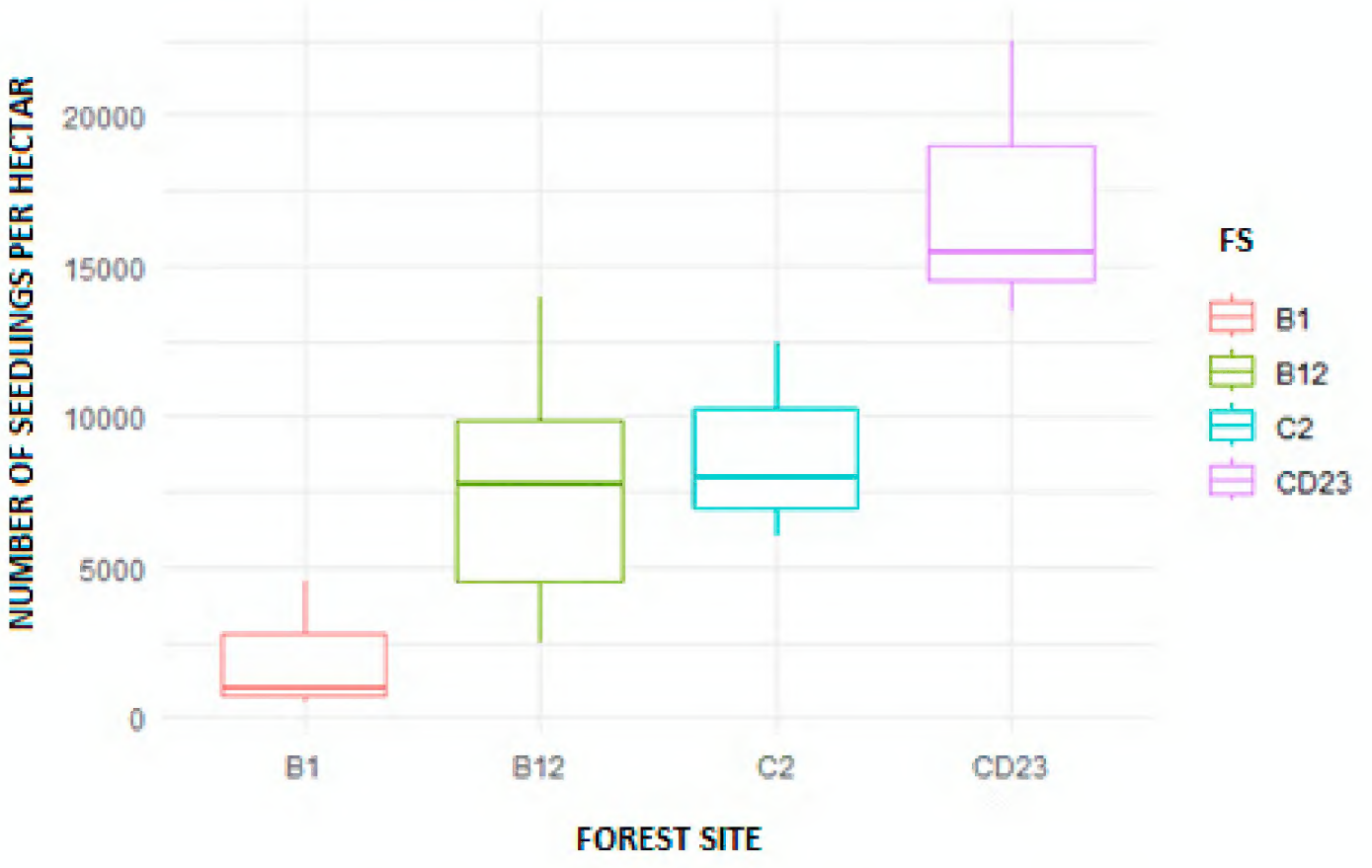

Fig. 4. Variation in the number of seedlings according to the forest site (FS)

The amount of understory does not vary statistically significantly according to the forest site ($p > 0.01$), i.e. the forest site does not affect the understory density. The ANOVA table for these parameters is as follows:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
FS	*3*	*160*	*53.4*	*0.039*	*0.989*
Residuals	*11*	*14991*	*1362.8*		

Figure 5 shows the dependency between the stands' density of the canopy and the amount of understory and seedlings in the plantations. The statistical analysis shows that the density of the canopy strongly influences the understory density (pval = 0.0001) and does not influence the seedlings density (pval = 0.4). The amount of understory was shown to decrease with increasing the density of the stands' canopy. The model is statistically significant and reasonable inferences can be made further, as the p value is much less than 0.05. The grey area in the figure graphically shows the confidence interval of the model. No significant linear relationship between the seedlings' amount and the canopy density is found. For illustrative purposes, this model is shown with a dashed line.

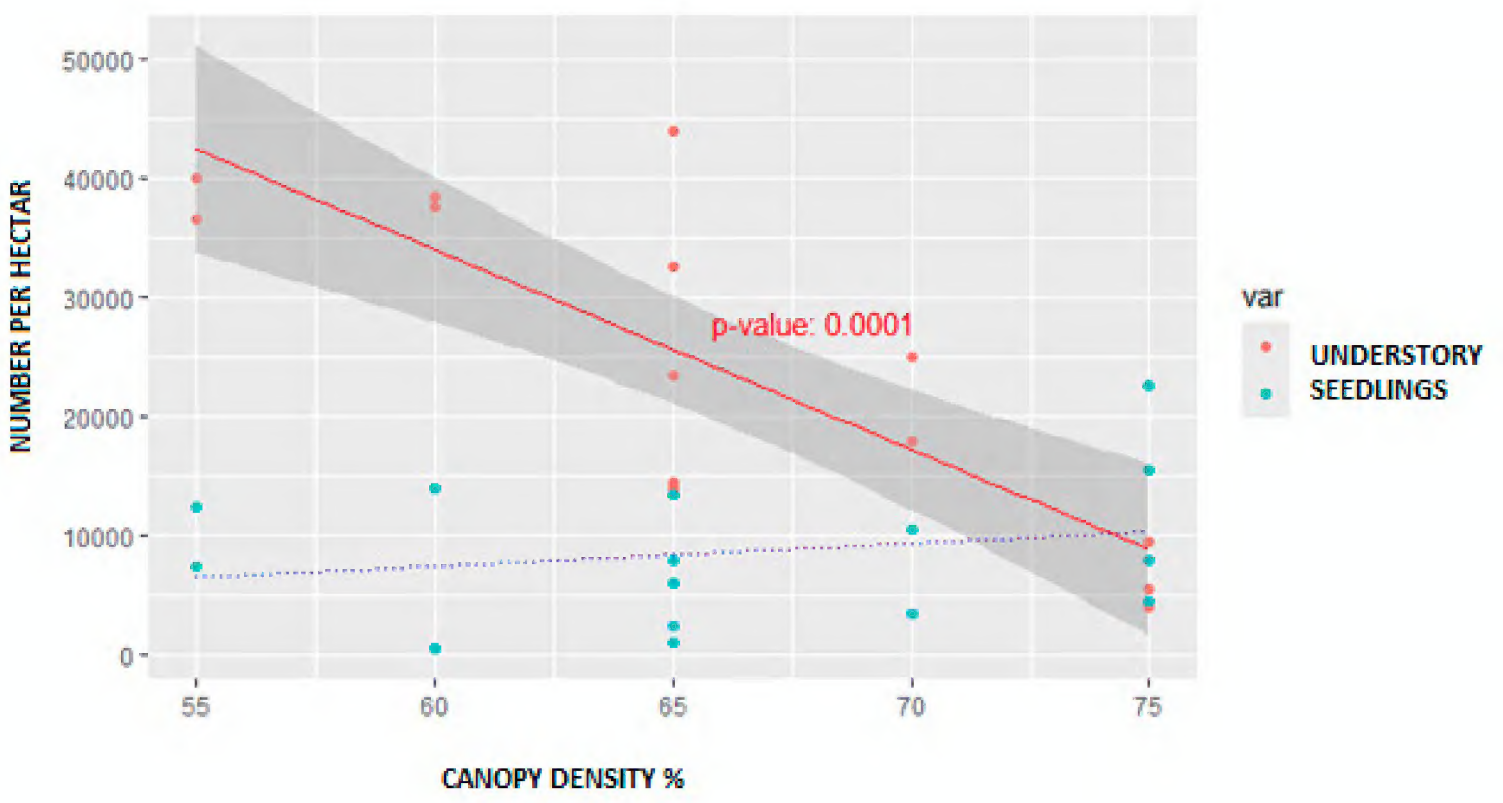

Fig. 5. Correlation between canopy density and amount of understory and seedlings

Figure 6 shows the dependency between the age of the plantation and the amount of understory and seedlings. The amount of seedlings has been shown to increase with increasing the stand age. The figure graphically shows the strong linear relationship (pval = 0.0021) between the two parameters and the confidence interval of the regression model. For the understory, no such linear relationship is confirmed (pval = 0.3), i.e. no linear relationship is found between its quantity and stand age.

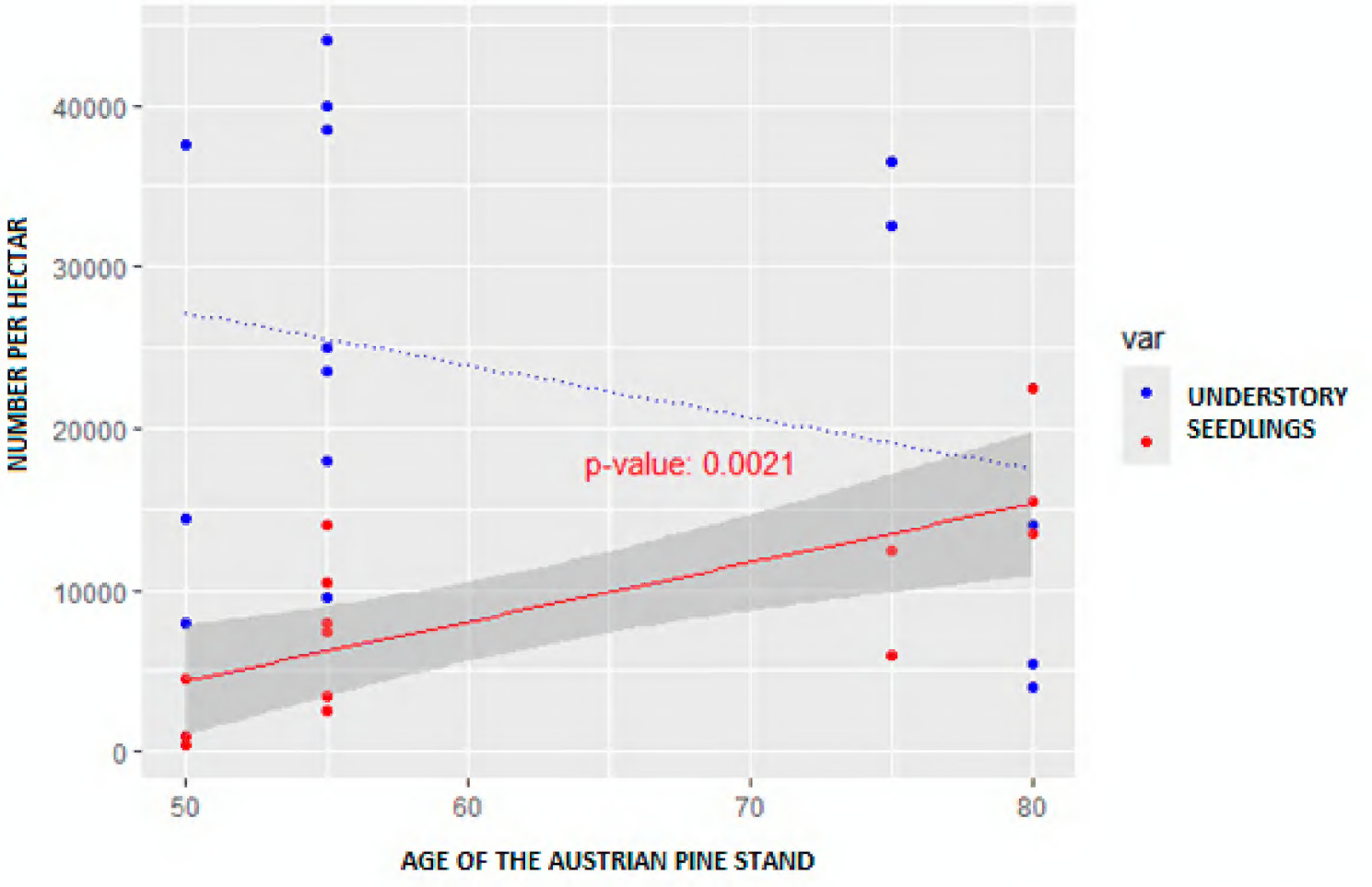

Fig. 6. Correlation between Austrian pine stands' age and quantity of understory and seedlings

Figure 7 shows the relationship between the stand age and the amount of understory and seedlings in stands with different canopy density. The analysis shows that a statistically significant regression model (pval = 0.0148) exists only for the number of seedlings at 0.7-0.8 percent density of the canopy. It is shown graphically with a solid brown line and confidence interval. For seedlings at slopes 0.5-0.6, the model has pval = 0.0899, i.e. just above the generally accepted 0.05 statistical significance threshold. It is shown graphically by a solid blue line without a confidence interval. The model could be interpreted as indicating the probable existence of a regression relationship, i.e. as a trend to be tested in the presence of a larger number of data. It can be said that the amount of seedlings in the stands increases with increasing age, with a faster increase at higher density of the canopy (0.7-0.8).

No statistical correlation was found between the amount of understory and the increase in stand age. However, there is a large difference between its average values for the two groups of density of the canopy. The amount of understory at density 0.7-0.8 is more than twice compared with that at 0.5-0.6 canopy density. The regression lines are shown graphically with dotted lines in red and green.

Welch Two Sample t-test
t = 3.9145, df = 12.806, p-value = 0.001826
alternative hypothesis: true difference in means is not equal to 0

mean of x	*mean of y*
31222.22	*11666.67*

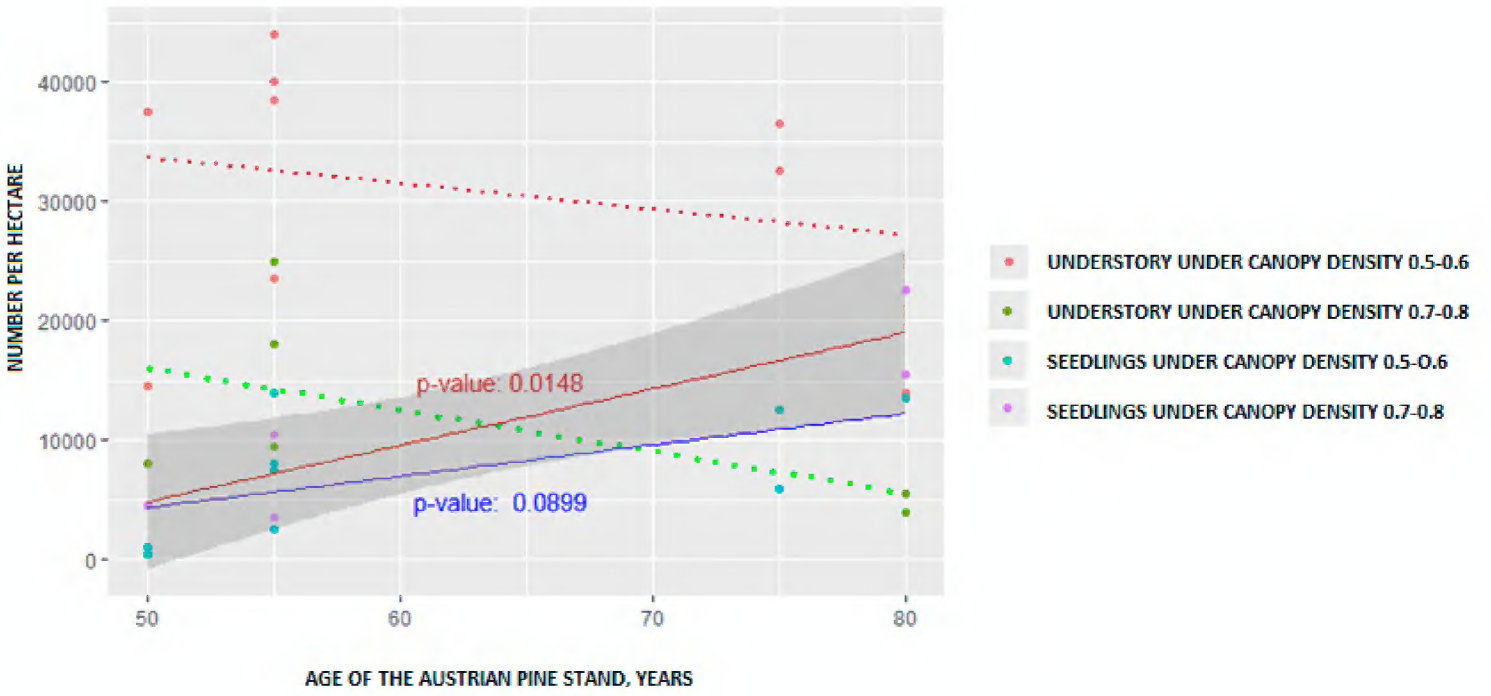

Fig. 7. Correlation between Austrian pine stands' age and quantity of understory and seedlings under different canopy density

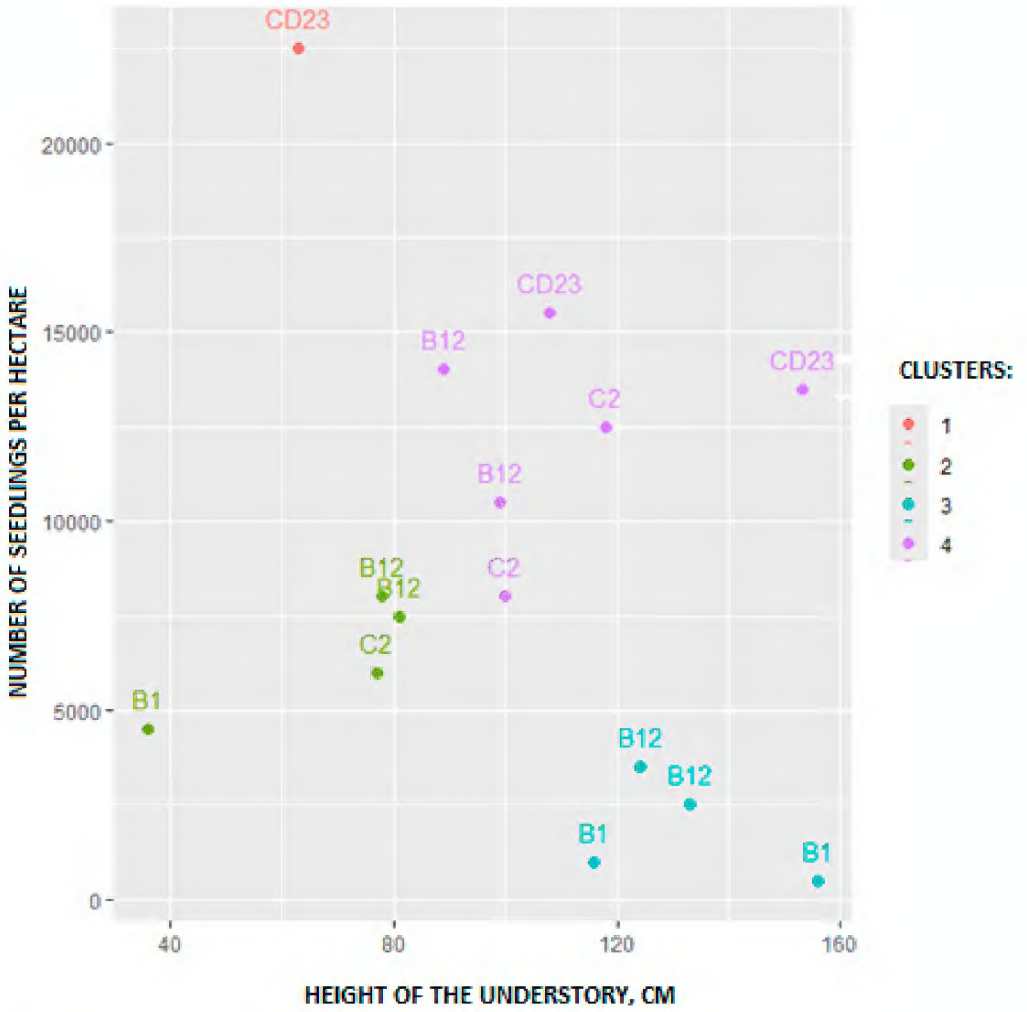

Fig. 8. Influence of understory height on the amount of seedlings

Figure 8 shows how understory height affects the amount of seedlings. An overall statistical model is absent, but four clusters are found. Clustering strongly reduces the heterogeneity (inhomogeneity) of the data, indicated by a several-fold reduction in the total variance as the sum of the variance across groups (4 clusters) compared to that without clustering (1 cluster).

The reduction in variance due to clustering allows the cluster number to be considered as a factor level, i.e., the impact of clustering can be examined by familiar methods of variance estimation, in this case ANOVA. For all analyses presented below, the requirement in ANOVA for constancy of variance was met.

For the variance of the amount of seedlings with respect to clustering, the ANOVA table is as follows:

	Df	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
cluster	*3*	*475312500*	*158437500*	*35.19*	*6.22e-06 ****
Residuals		*11*	*49520833*		*4501894*

I.e., in the indicated clusters the mean values of the amount of seedlings are shown to be significantly different. This is to be expected, as the k-Means analysis that was previously performed identifies groups by tracking the possible reduction in within-group variance.

For the variation of understory height with respect to clustering, the ANOVA table is as follows:

	Df	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
FS	*3*	*10309*	*3436*	*7.808*	*0.00454 ***
Residuals	*11*	*4842*	*440*		

I.e., understory height was also statistically shown ($p < 0.01$) to vary with respect to clustering.

The two results are visualized by box plot diagrams for the two variables (Fig. 9):

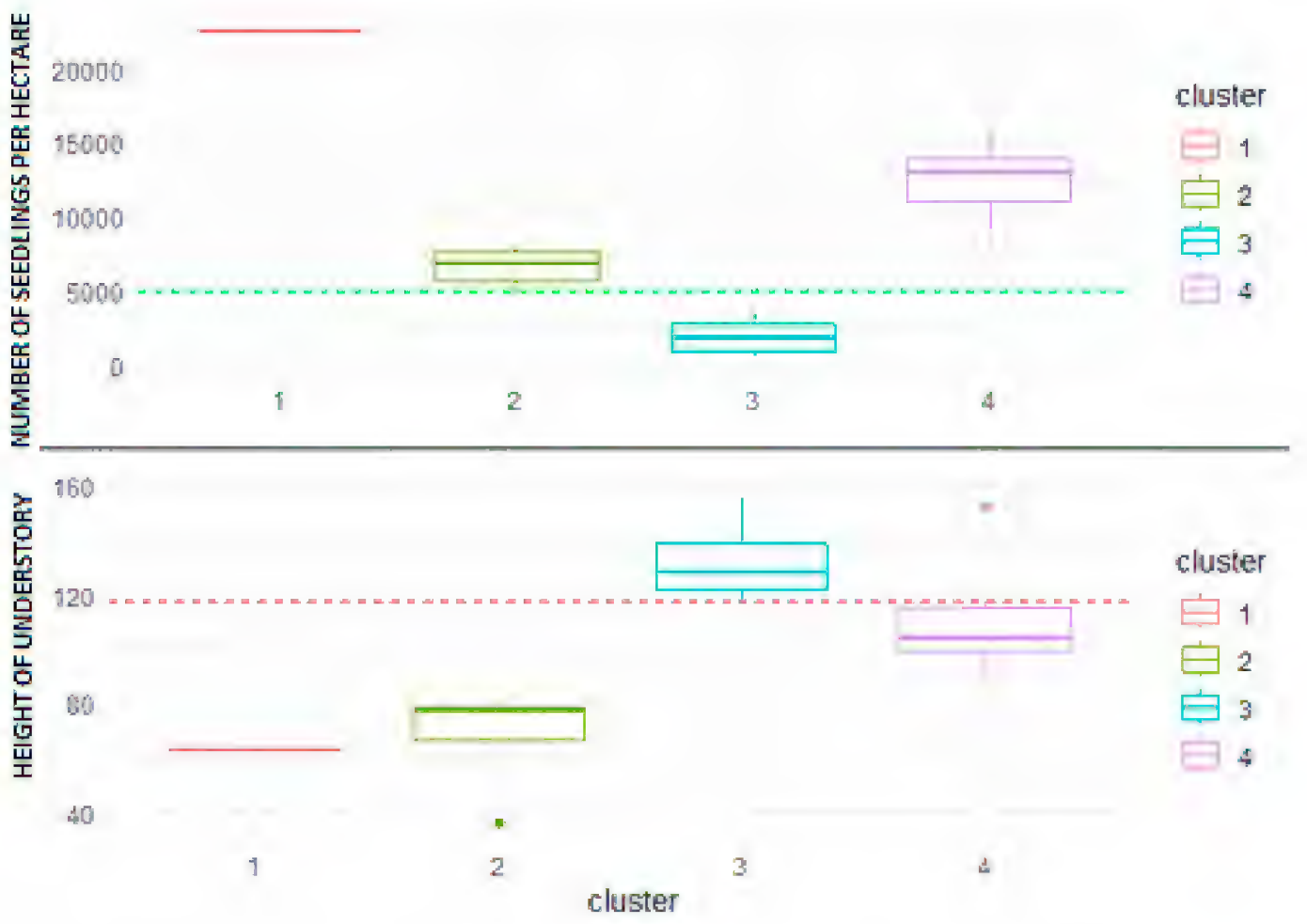

Fig. 9. Variation of the seedlings amount and understory height per clusters

The following conclusions can be drawn from Fig. 8 and 9 with the accompanying analysis:

- The data can be grouped into 3 clusters. Cluster 1 is not considered as a separate group as it includes only one sample plot (SP). In two of the clusters (No.#2 and No.#4) the understory height is less than 120 cm and the amount of seedlings is more than 5000 pcs/ha. In cluster No.#3 the understory height is above 120 cm and the amount of seedlings is below 5000 pcs/ha.
- Since the IQR of the box plot diagrams (Fig. 9) do not overlap, the differences between the means of the clusters are statistically proven.
- For the single observation with maximum value of the amount of seedlings (cluster No.#1), the conclusion remains valid.

Therefore, for the dataset collected, it can be assumed to be a statistically proven hypothesis that for understory height below 120 cm the amount of seedlings is above 5000 pc/ha and for understory height above 120 cm the amount of seedlings is below 5000 pc/ha.

Discussion

From a silvicultural point of view, it is important to establish where and when the seedlings of the economically important tree species occur in Austrian pine stands, and whether it is in a quantity that allows them, with or without silvicultural intervention, to form a new generation of forest. On poor forest sites (B_1), the amount of seedlings is between 500 and 4 500 pcs/ha, which is extremely insufficient for full regeneration of the forest (Fig. 4). The main reasons are the absence of relevant broadleaved species in the stand composition, the dense understory and poor growing conditions, which severely hinder the emergence and survival of the seedlings. On medium-fertile and fertile forest sites ($B_{1,2}$ and C_2) the amount of seedlings is higher (between 5000 and 15 000 pcs/ha). It varies widely across the sample plots, indicating that it is unevenly distributed across the plantation area. Its quantity is insufficient for complete regeneration of the area and silvicultural interventions should be concentrated in areas where it is in sufficient quantity. On medium to fertile forest sites ($CD_{2,3}$) the amount of seedlings is between 15,000 and 25,000 p/ha. Here the growing conditions are favorable and there is no obstacle to its germination and survival.

According to forestry regulations in Bulgaria (Ordinance No.8 on forest felling, Supplementary Provisions § 1, item 6), the sufficient amount of seedlings for natural regeneration of oaks before the final phase of regeneration felling is 21,000 pcs/ha. For the other species that have a significant contribution to the seedling composition in the stands under study (Turkey oak, Oriental hornbeam, Beech, Linden), the sufficient amount of seedlings is considerably less, between 6 000 and 18,000 pcs/ha. This means that it is present in the stands of medium-fertile forest sites, as well as in poor forest sites. Dodev (2020) draws a similar conclusion regarding the amount of oak seedlings in *Carpinus orientalis* forests.

The Manna ash, which is highly dominant in the understory, is an undemanding species to soil fertility. It can grow on deep and fertile as well as poor and dry soils (Delkov, 1988). Caudullo, de Rigo (2016) found that it thrives better on poor soils, as it suffers competition from other deciduous tree and shrub species on more fertile ones. Its strongest advantage is its drought tolerance, which is due to its sub-Mediterranean-Illyrian character (Wallmann, Stingl, 2011; Trájer et al. 2016).

It can be concluded that on medium fertile and fertile sites the silvicultural aim should be to completely regenerate the area with native and economically valuable broadleaved species, while on poor sites the Manna ash will be part of the new stand. There are positive aspects to this as well, as its participation will improve the anti-erosion functions of the stands and their resistance to diseases and pests (Nodenska, 1971). Moreover, Erbakamov et al. (1996) found that Manna ash could also be found in straight-stemmed and large-sized forms in which the stem section suitable for construction timber is 8-10 (12) m long and over 18 cm in diameter (even over 30 cm). If properly managed, on poor and dry sites, the Manna ash can co-dominate with the main species, not displacing them but growing alongside them.

There is a clear inverse relationship between the canopy density and the amount of understory (Fig. 3). Manna ash is shade-tolerant at a young age, and later its tolerance to shading decreases (Delkov, 1988). Its quantity is half as much at 0.7-0.8 canopy density compared to its quantity at 0.5-0.6 at the same age of the stand (Fig. 7). Therefore, maintaining a high density of the stands' canopy does not allow formation of a dense understory.

Zlatanov (2003) found that Manna ash understory largely appears at 30-40 years of age in the Austrian pine plantations. He found that in terms of height increment and vigor, individuals growing at 0.6-0.8 density of the canopy are not significantly inferior to those developing at much lower density (0.2-0.4). The presence of a greater number of suppressed individuals is observed only in dense understory groups. This, as well as Figure 4, indicates that, in addition to a higher density stand canopy, it is necessary to wait a certain time for the understory self thinning to begin.

The amount of the seedlings rises with the increase in stand age (Fig. 6). In contrast to the understory, as the canopy density of the pine layer increases, the amount of seedlings not only does not decrease, but even increases (Fig. 7). A likely explanation for this is the reduced amount of understory. Thus, its suppressive influence on the seedlings is reduced, and a greater amount of it manages to survive. At higher density canopy (0.7-0.8) its increase is significantly faster. This indicates that maintaining a canopy with higher density prevents the emergence and development of dense understory, while not reducing the amount of the seedlings that emerge. According to Damyanov (1971), at a stand canopy of 0.6-0.7, the soil remains in the best condition, the oak seedlings are strengthened at maximum and the understory, which overgrows the seedlings, reduces its vigor.

In this case, the so-called "silvicultural patience" is an effective strategy. It means waiting for the right conditions because the ratio between the amount of understory and seedlings changes in favor of the seedlings as the stands age. Of course, this is

sufficient if the health condition of the stand permits waiting for such an age and the intense decay of the main stand has not begun, i.e. high density of the canopy is maintained. At 65 years of age and a canopy of 0.7-0.8, the amount of seedlings and understory level off, and thereafter the amount of the seedlings is more than the understory (Fig. 7). The results of the figure indicate the approximate age (65 years) after which it is appropriate to proceed with felling for transformation of stands with a dense canopy of the understory. Zlatanov (2006) found that regular thinnings in Austrian pine plantations of moderate to high intensity favors the formation of deciduous canopy layer by the age of 69-75 years, with a number of about 10,000 saplings/ha and a dominant height of up to 2.8 m.

Kostov et al. (2023) support differentiated rotation age for Scots pine artificial plantations according to their degree of ecosystem fit. For plantations with a relatively good ecosystem fit, they recommend a rotation cycle of 100 yr. According to them, the regeneration process can be extended up to 30 yr in order to optimally assimilate the productivity of the habitat and provide permanent forest cover through incremental or group-stepwise harvesting. For Scots pine artificial plantations with complete absence of ecosystem compliance, they consider that the rotation age should not be longer than 60 years.

A critical period for the successful transformation of coniferous plantations is the survival and strengthening of the oak seedlings in the first years after regeneration felling. They need to be taken care of during the first 10 years until they strengthen and become competitive with understory species (Popov et al., 2024). However, in the first years, the understory definitely outgrows and suppresses the seedlings and thinning measures are much needed.

Gyudorova et al. (2022) investigated the efficiency of different ways of controlling the Manna ash understory - cutting the stems at the base, cutting the stems 50 cm from the base, breaking the stem tip and grazing. The results show that the following year the tree recovers almost completely. Of the mechanical control measures, only cutting at the base resulted in a slight reduction in its numbers (by about 10%). Cutting back the stems at 50 cm height and breaking off the tips even increases its density, as the damaged stems continue to grow and vegetate and side shoots emerge from them (the so-called 'hydra effect'). Grazing gives the best result. It results in a threefold reduction in the amount of Manna ash stems, but in this case it is completely inapplicable, as the animals will also girdle the valuable oak seedlings. Even though the Manna ash recovers after a single application of the measures described, thinning leads to an increase in the amount of seedlings in all of the sample areas, and is strongest where the Manna ash is cut at the base of the stem.

At the same time as the regeneration felling for transformation is carried out, the understory needs to be cut. Timely removal of the Manna ash shoots afterwards is also critical. If the understory is allowed to grow too tall, it will cause suppression of the oak seedlings, and eventually the future stand will be formed of inferior species. From Figures 8 and 9 it can be seen that the height of the understory should not be allowed to exceed 120 cm until the seedlings form a canopy, as this leads to a severe

reduction in their amount. Reaching this height from the Manna ash understory can be used as a guide for the need to carry out the initial thinning.

Our observations show that in abrupt illumination the Manna ash in the understory gives way to other concurrent species. If confirmed, this feature of the species can also be used in silvicultural measures for conifer plantation transformation.

Conclusion

With regard to the Austrian pine plantations with understory of Manna ash, which were established in the mountains around Sofia up to 850 m a.s.l., the following conclusions can be drawn:

- Their transformation into natural deciduous stands is a natural and inevitable process that is currently occurring. The seedlings consist mainly of native oak species and their natural companions. However, the available understory is outgrowing and suppressing the seedlings. The natural transformation can be a very long process, which is unacceptable from a forestry perspective. Therefore, it needs additional silvicultural care.
- The amount of seedlings is dependent on the forest site and increases rapidly as growing conditions improve. On poor and dry forest sites (type B_1), the amount of seedlings is very small (up to 4500 pcs/ha) in all sample areas. On medium-fertile and fresh sites ($B_{1,2}$ and C_2) the number of seedlings is between 5000 and 15000 pcs/ha. On the medium fertile to fertile sites (type $CD_{2,3}$) the amount of seedlings is between 15000 and 25000 pcs/ha.
- Understory density decreases rapidly as the density of the canopy stand increases. At a canopy density of 0.7-0.8, the understory is more than twice less than at a canopy of 0.5-0.6 density. The amount of seedlings emerging is not significantly dependent on the canopy density.
- With increasing stand age, the amount of seedlings increases while that of the understory decreases. At 65 years of age and a canopy of 0.7-0.8 the amount of seedlings and understory equalize, and thereafter the seedlings are more than the understory.
- Understory height above 120 cm results in severe suppressing and seedling dieback. It is too likely that seedling suppression is also dependent on understory cover and further research is needed in this direction.

Recommendations:

Based on these findings, the following recommendations can be made:

- For the successful transformation of Austrian pine plantations it is necessary that their management is aimed at creating conditions for emergence and survival of as many seedlings of desired tree species (mainly oaks) as possible while limiting the emergence and development of the understory vegetation. The Austrian pine seedlings as part of the desirable species should be taken care of whenever it is present.

- To this end, the pine stands should be managed at a canopy density above 0.6 for as long as possible. Their timely thinning is necessary to provide growing space and improve the health of the main stand.
- If sufficient amount of seedlings is available, regeneration felling for transformation can begin. It is usually available after 65 years of the stand's age. On the medium fertile to fertile sites (type $CD_{2,3}$) seedlings are present throughout the area, on sites with worse conditions (types B_1, $B_{1,2}$, C_2) they are unevenly distributed. However, usually that regeneration is an uneven process. To implement group regeneration felling, it is sufficient to have individual patches with sufficient number of seedlings. In places with insufficient amount of seedlings, the strategy can be waiting for their appearance, if the condition of the main stand allows it, or alternatively, the process can be replaced with planting of suitable species.
- It is extremely important that the release cutting starts at the same time as the regeneration felling. The most appropriate measure is to cut the understory at the base of the stem. Timely thinning is necessary until the seedlings form a canopy. The number of cuttings depends on the height of the understory, which should not be allowed to exceed 120 cm until the desired species begin to rapidly increase in height and outgrow the understory.

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